The hyperspectral Mission DESIS Entering the operational Phase

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3 I2R Innovative Imaging and Research Corp, Stennis Space Center, USA

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Teledyne

Teledyne Brown Engineering (USA) and **DLR** have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (**DESIS**) from the Teledyne-owned Multi-User System for Earth Sensing (**MUSES**) Platform on the ISS

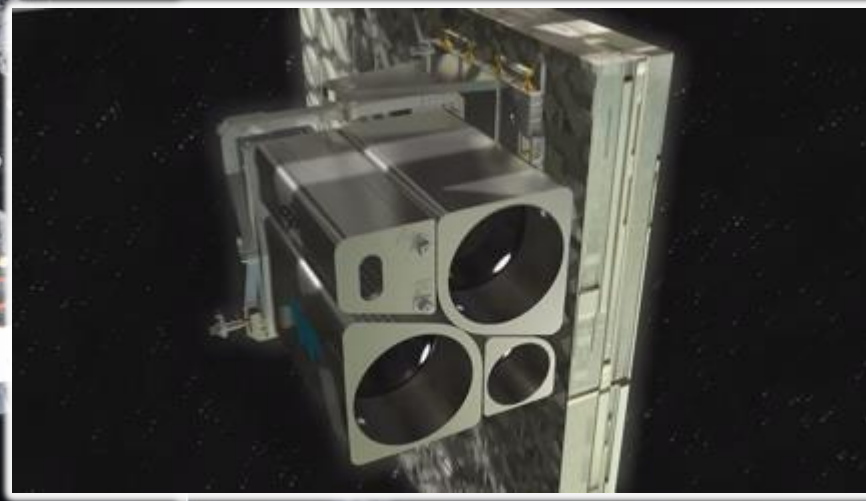
MUSES provides accommodations for two large and two small hosted payloads and provides **core services** for the instruments like

- **Position** via GPS (1 Hz)
- **Attitude** via Startracker + MIMU (10 Hz)
- **Master time** (acc. <150 µsec)
- **2 Gimbals** ±25° for/back; 45° backboard; 5° starboard
- **Downlink** 225 Gbit / day Ku band

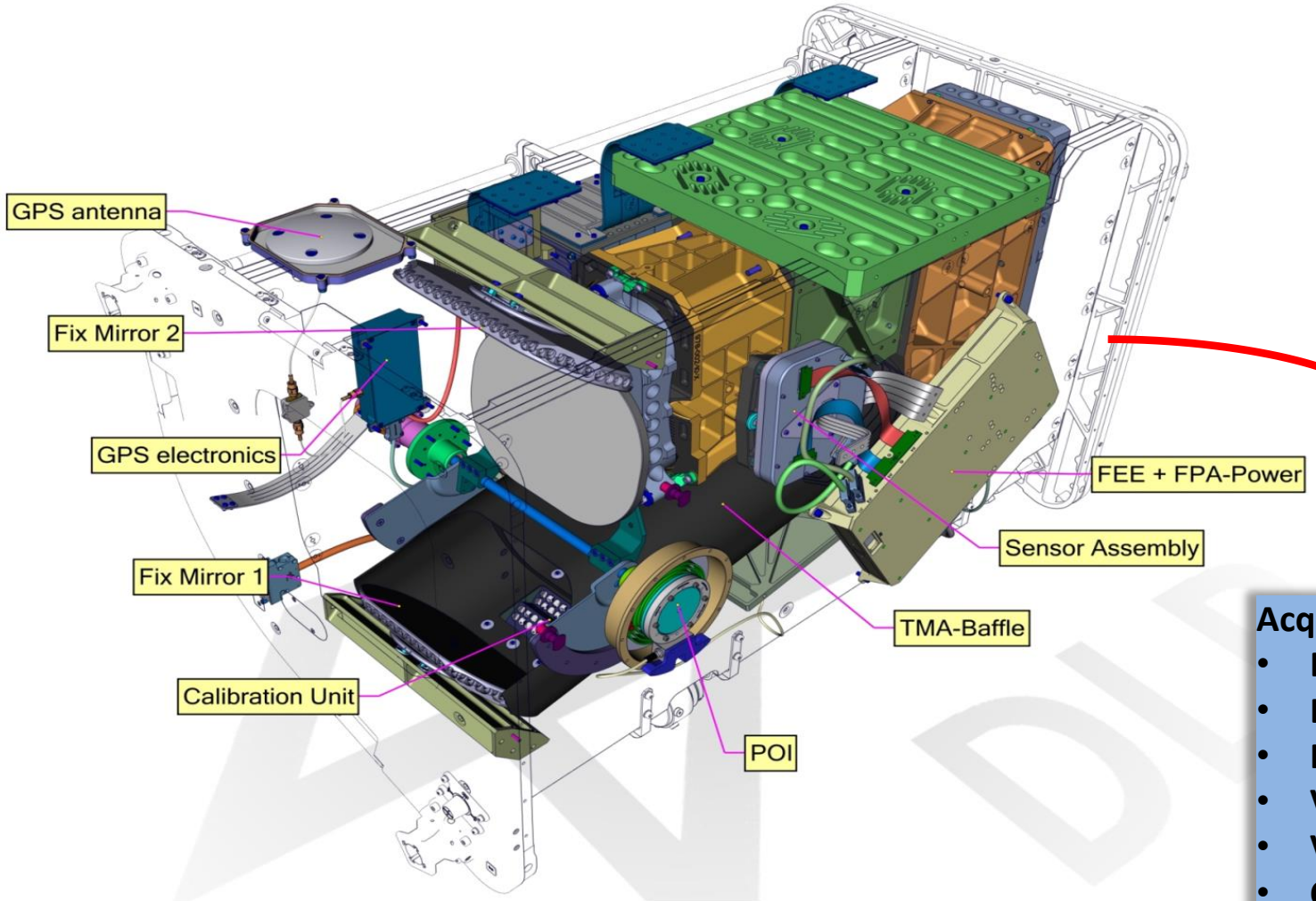
DLR developed the hyperspectral sensor **DESIS**, which is currently the first payload

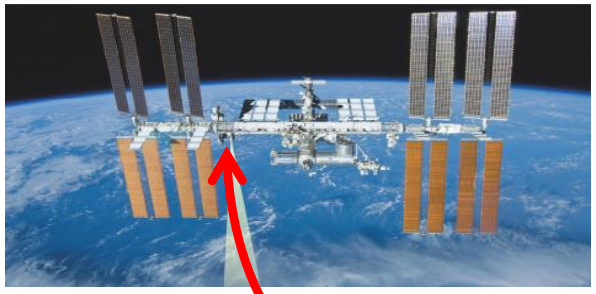
DLR established the Ground Segment and licensed the SW processors to Teledyne running in an Amazon Cloud

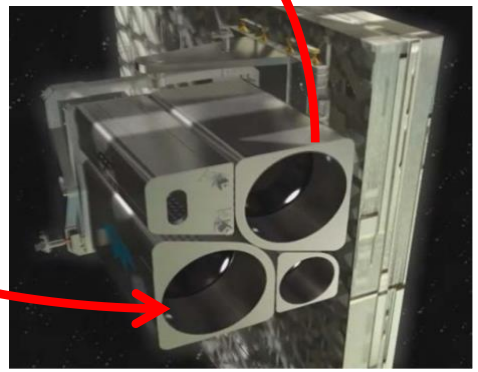
- onBoard Calibration
- Product Generation
- Data Archiving@DLR
- Data Distribution@DLR



DESIS Instrument







Acquisition Modes

- **Earth –** *user deliverable product*
- **BRDF (e.g. -15°, 0°, +15°) -** *user deliverable product*
- **Forward Motion Compensation –** *experimental*
- **Var. HW binning modes (no, 2,3,4) –** *replaced by SW binning*
- **Var. gain modes (LG2, HG10) –** *fixed during commissioning*
- **Calibration (spectral, radiometric)**
- **Dark Current (before & after datatake)**

FEE: Front End Electronic
FPA: Focal Plane Array
TMA: Three Mirror Anastigmat
POI: Pointing Unit

Mission Instrument	ISS/MUSES DESIS	EnMAP HSI (2 instruments)
Off-nadir tilting (across-track, along-track)	-45° (backboard) to +5° (starboard), -40° to +40° (by MUSES and DESIS)	-30° to +30°, 0° (by EnMAP)
Spectral range	400 nm to 1000 nm	420 nm to 2450 nm
Spectral Sampling (res., acc.,bands)	2.55 nm, 0.5 nm, 235 118 (bin 2), 79 (bin 3), 60 (bin 4)	6.5 nm, 0.5 nm (VNIR), 10.0 nm, 1.0 nm (SWIR)
Radiometry (res., acc.)	13 bits, ~10%	14 bits, 5%
Spatial (res., swath)	30 m, 30 km (@ 400 km)	30 m, 30 km
SNR (signal-to-noise)	195 (w/o bin.) / 386 (4 bin.) @ 550 nm	500 @ 495 nm, 150 @ 2200 nm
Instrument (mass)	93 kg	350 kg
Capacity (km, storage)	2360 km per day, 225 GBit	5000 km per day, 512 GBit

Mission Instrument	ISS/MUSES DESIS	EnMAP HSI (2 instruments)
Target lifetime	2018-2023	2021-2026
Satellite (mass, dimension, usage)	455 t, 109.0×97.9×27.5 m^3 (multi-purpose)	1 t, 3.1×2.0×1.7 m^3 (single-purpose)
Orbit (type, local time at equator, inclination, height, repeat cycle)	not Sun-synchronous, various, 51.6°, 320 km to 430 km, no repeat cycle	Sun-synchronous, 11:00, 98.0°, 653 km, 398 revolutions in 27 days
Coverage	55° N to 52° S	74° N to 74° S
Revisit frequency	3 to 5 days (average)	≤ 4 days, ≤ 27 days (±5° tilting)

Note: FPA of DESIS is the same as for EnMAP VNIR
Note: high overlap in on-ground processing

=> DESIS can be also regarded as a precursor of EnMAP

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DESIS (DLR Earth Sensing Imaging Spectrometer)
MUSES (Multi-User System for Earth Sensing)
ISS (International Space Station)

Current Status of the imaging spectrometer DESIS on the multi-payload platform MUSES installed on the ISS

2014 / 2015
MUSES / DESIS mission starts

7. June 2017
MUSES installation on ISS

29. June 2018
DESIS launch from Cape Canaveral to ISS via SpaceX Dragon

27. - 28. August 2018
Unpacking of DESIS and installation in MUSES

- Leaving Commissioning Phase, but some remaining tasks
- Commercial Data delivery already started

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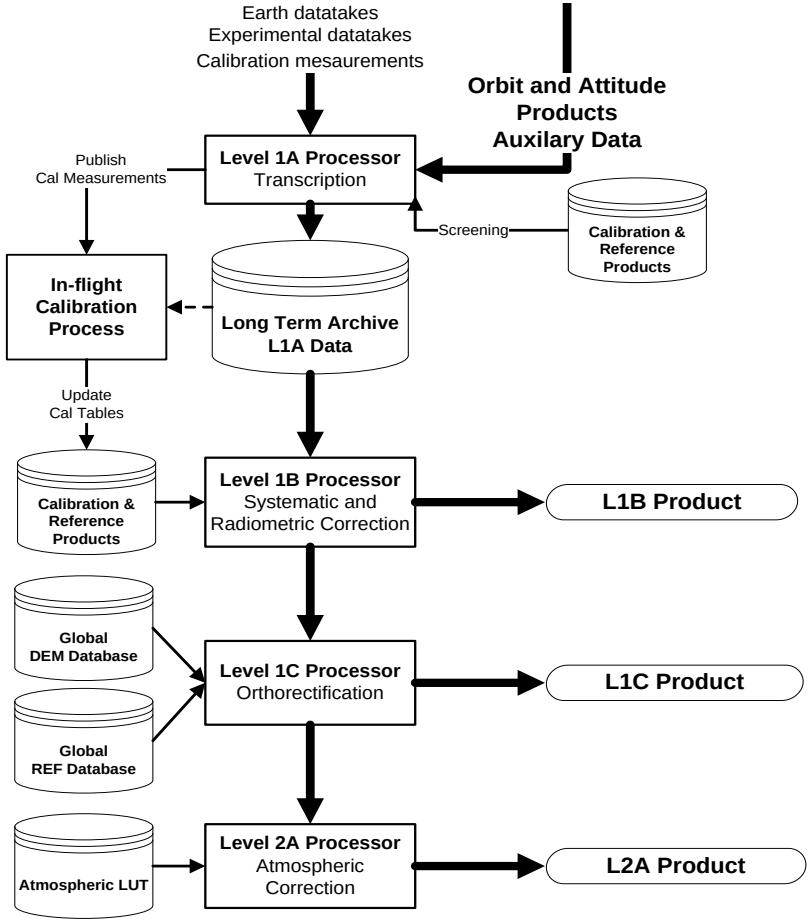
Data Processing
Which products are getting the user



Products:

- **Level 0 (L0)**
  - Raw data (Datatakes up 100 tiles 30x30 km², trajectory files, DC)
- **Level 1A (L1A)**
  - Tiled images, browse image, metadata, quality flags <= archived.
- **Level 1B (L1B)***
  - Top of Atmosphere (TOA) radiance (W.m-2.sr-1.µm-1)
  - Systematic and radiometric correction (rolling shutter, smile, suspicious pixels,….)
  - All metadata attached for further processing
- **Level 1C (L1C)***
  - Level 1B data ortho-rectified, re-sampled to a specified grid
  - Global DEM (Aster GDEM v2), sensor model refinement using global reference image (Landsat-8 PAN with acc. 18m CE90)
- **Level 2A (L2A)***
  - Ground surface reflectance (i.e. after atmospheric corrections)
  - With and w/o terrain correction

Processors at the Ground Segments

- Fully automated
- Run ‘on-request’ over archived data
- Two instances: one at Teledyne (Amazon Cloud), one at DLR. Same processing

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* Delivery product

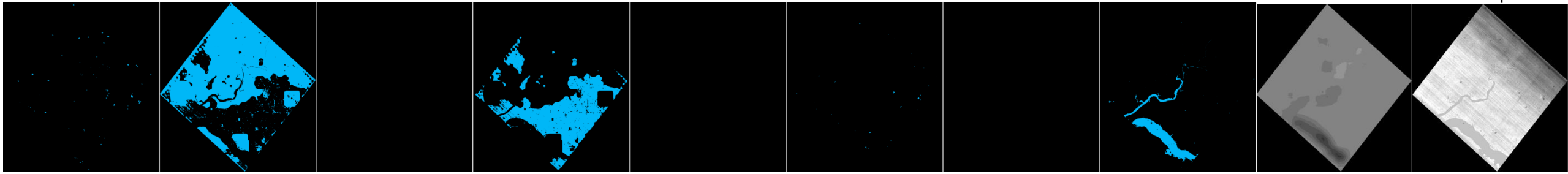
Quality Layers and Metadata

Quality Layer (Geotiff)	L1A	L1B	L1C	L2A
Dead pixels		X	X	X
Suspicious pixels		X	X	X
Too high radiance level		X	X	X
Too low radiance level		X	X	X
Shadow				X
Clear Land				X
Clear Water				X
Haze over land				X
Haze over water				X
Cloud over land				X
Cloud over water				X
Aerosol optical thickness				X
Perceptible water vapour				X
Detector Map (Digital Number)	X			
Detector Map (Radiance Level)	X			

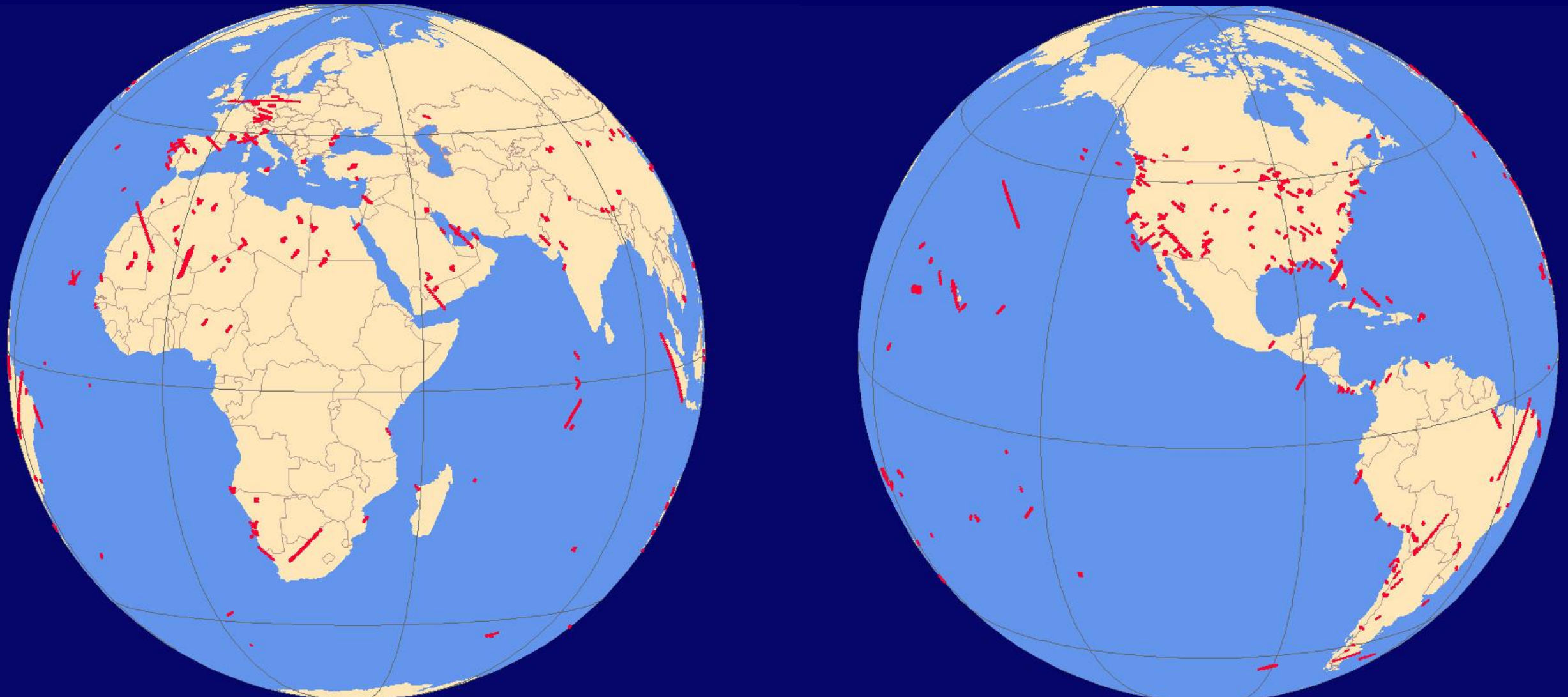
Metadata (xml file)

- Dead Pixels
  - generated through calibration
- Suspicious pixels
  - Generated by comparison between measured radiances and calibration
- Data Screening
  - Temperatures, Voltages, Currents, CRC, Dark Currents
- Geometric accuracy
  - Subset of matching points with reference
- Bad columns/lines (based on detector maps)
  - Generated by statistical tests
- Smile Indication
  - Based on Absorption Bands (like O2 at 760 nm)

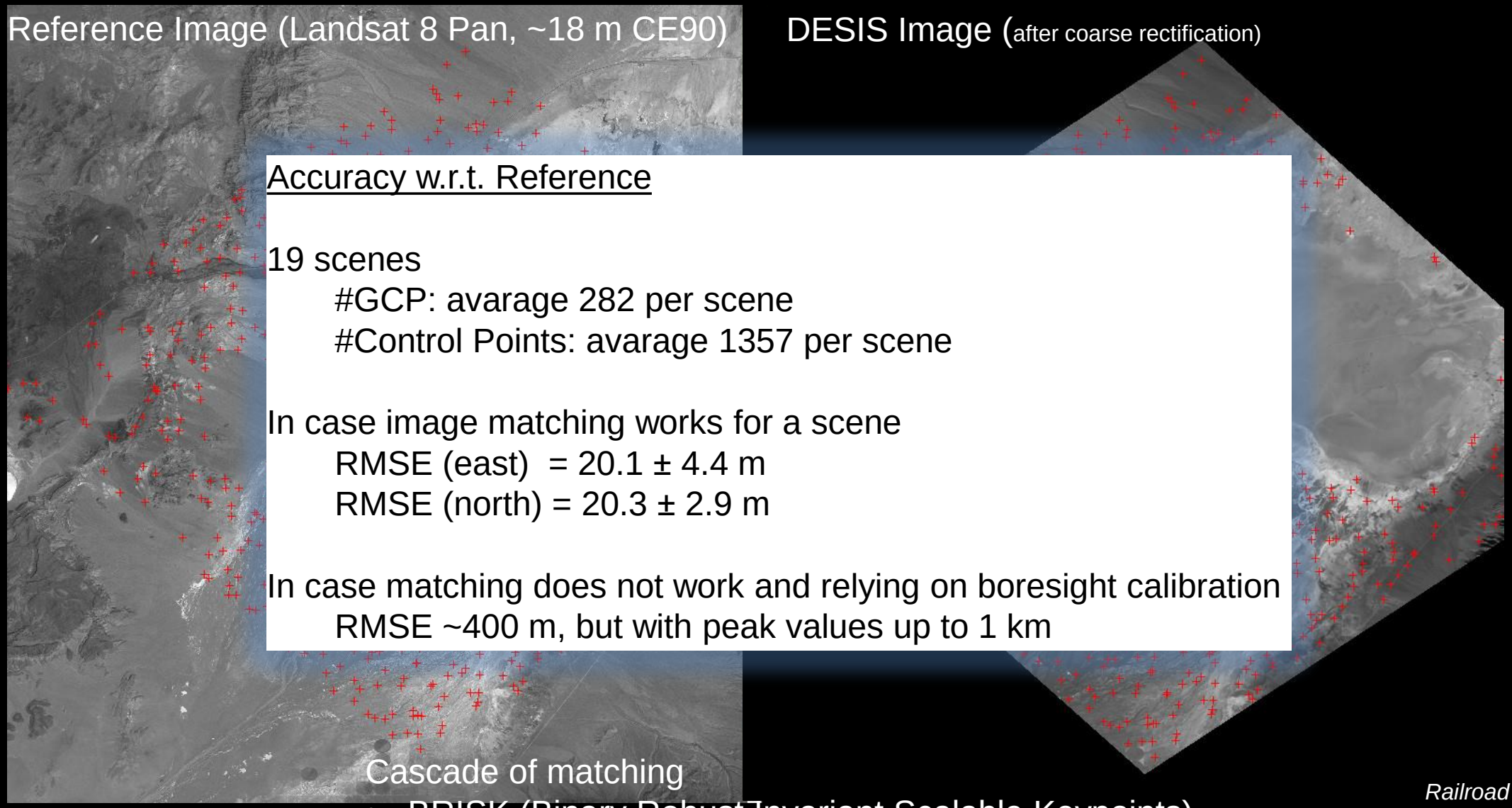
Shadow | Clear land | Snow | haze over land | haze over water | Cloud over land | Cloud over water | Clear water | Aerosol optical thickness | Water vapour



During Commissioning about 3100 products are acquired and processed



Commissioning Phase Activities – Geometric Calibration & Accuracy



Accuracy w.r.t. Reference

19 scenes
- #GCP: avarage 282 per scene
- #Control Points: avarage 1357 per scene

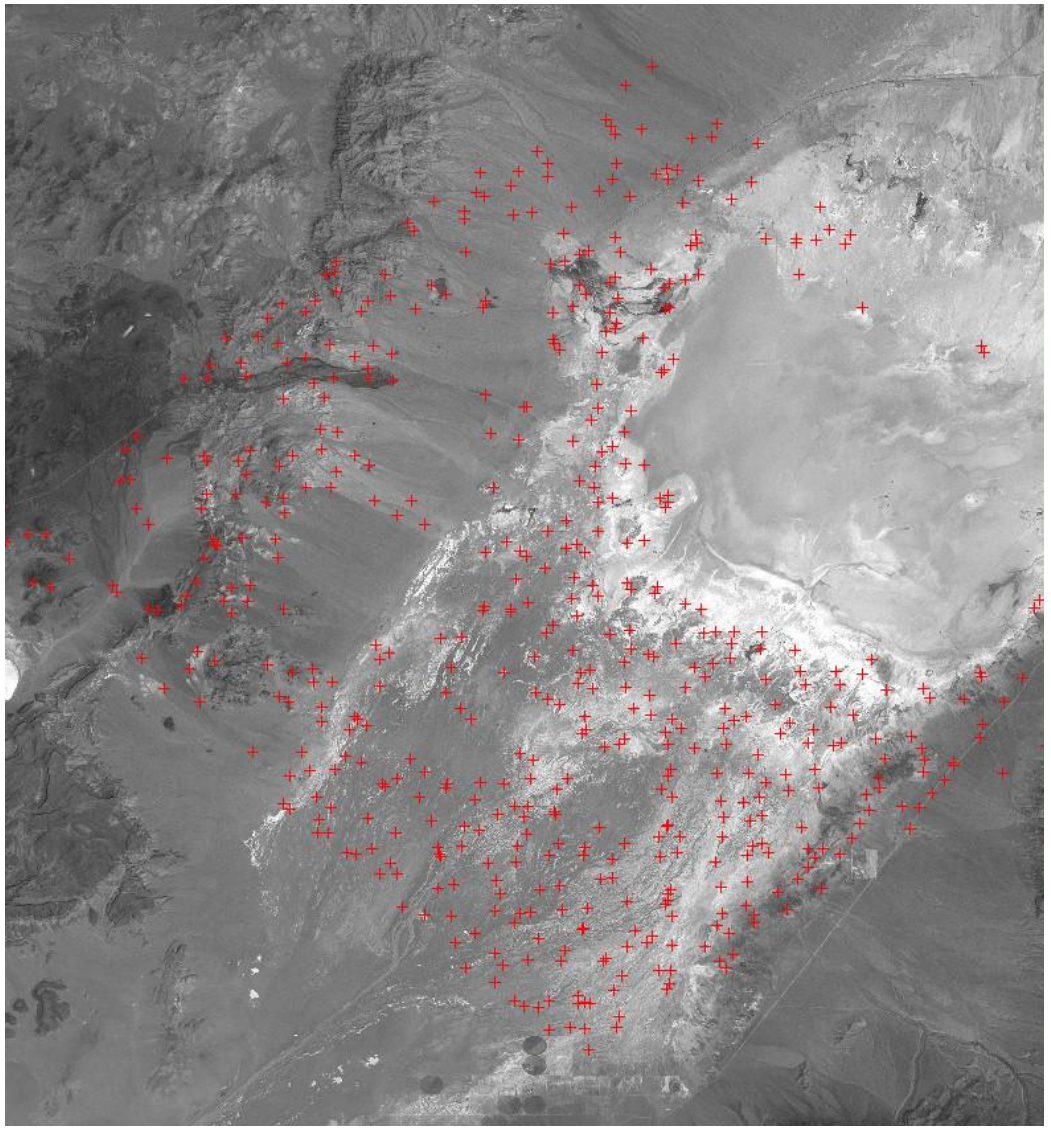
In case image matching works for a scene
- RMSE (east) = 20.1 ± 4.4 m
- RMSE (north) = 20.3 ± 2.9 m

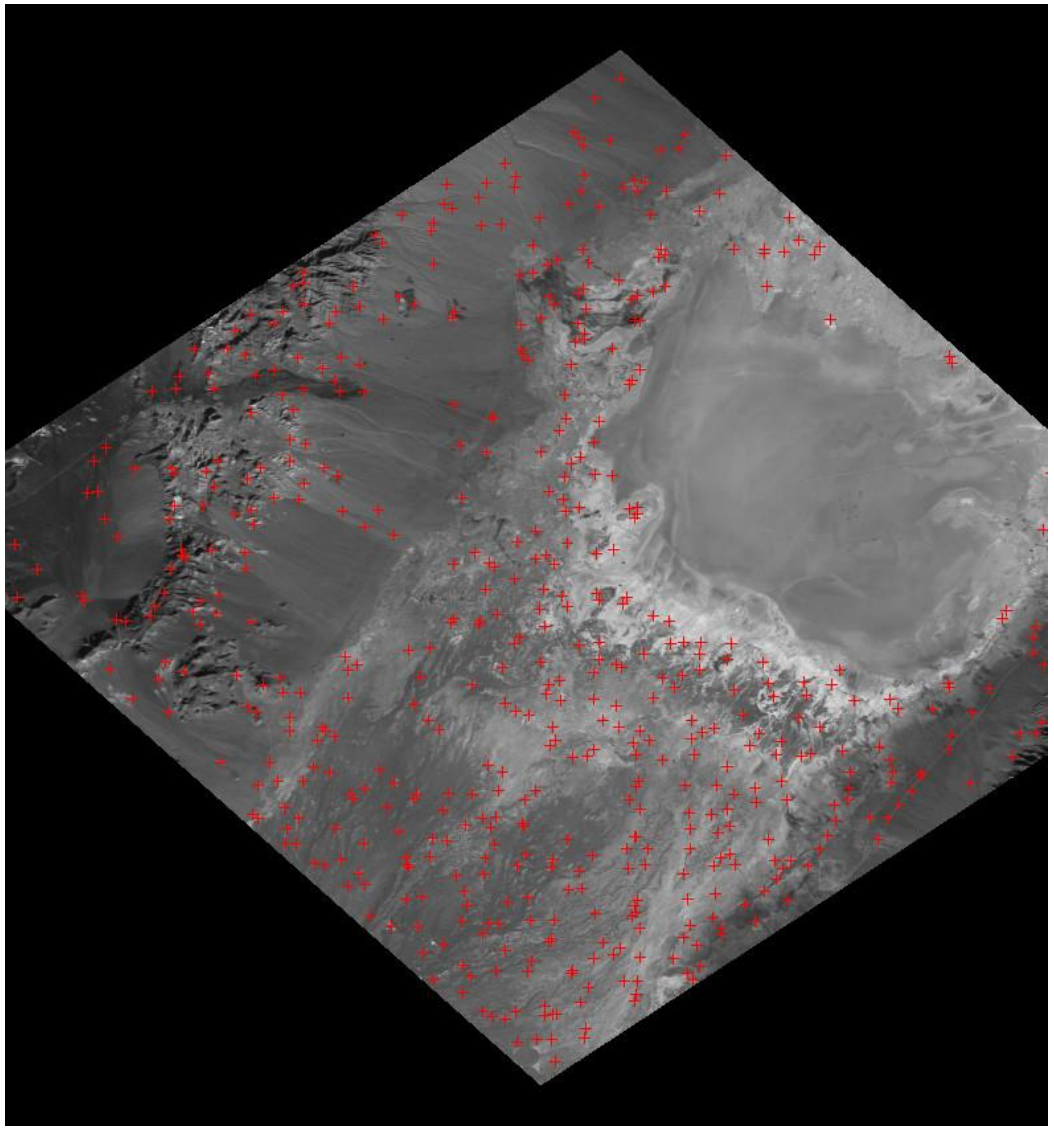
In case matching does not work and relying on boresight calibration
- RMSE ~400 m, but with peak values up to 1 km

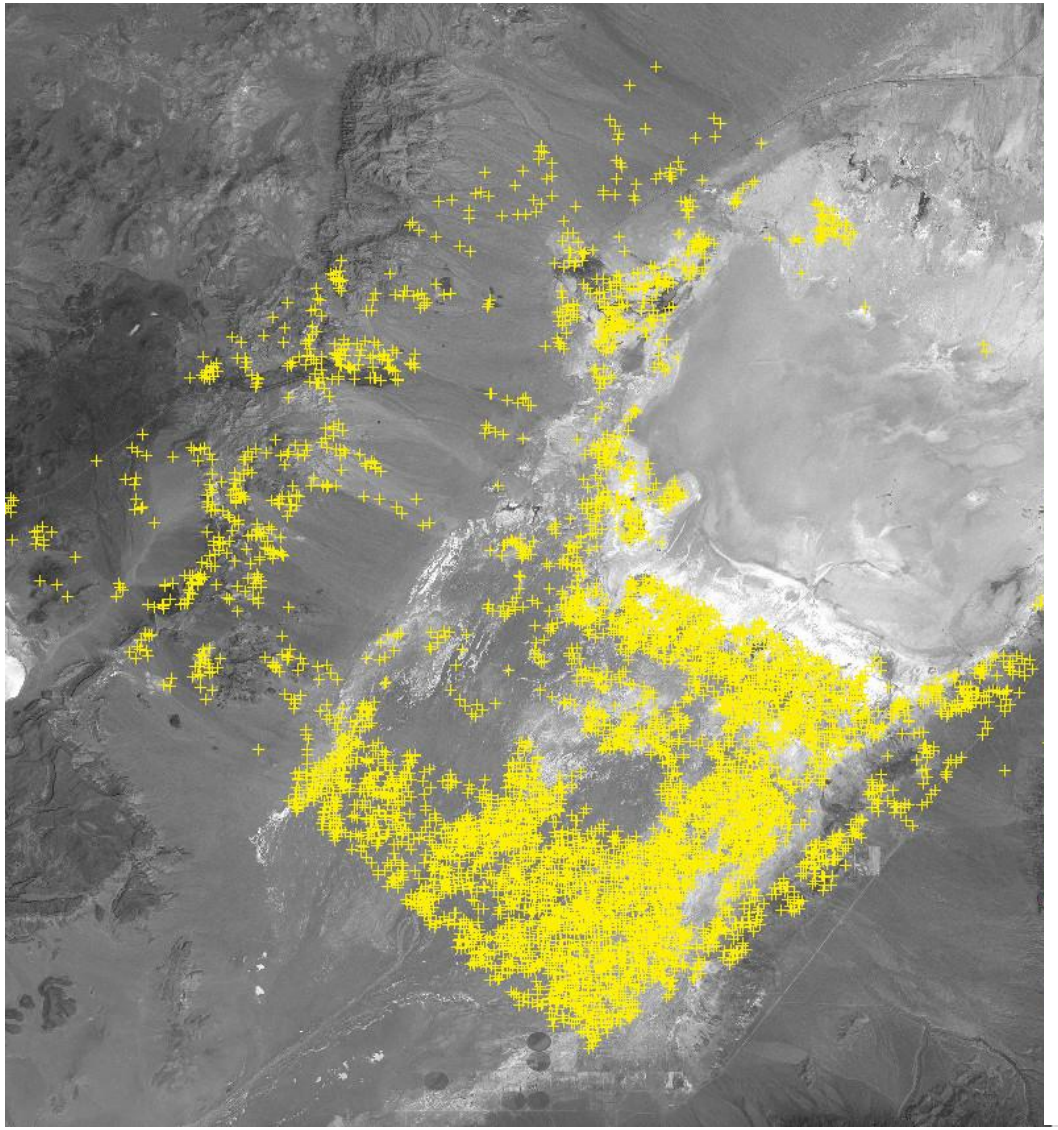
Cascade of matching
- BRISK (Binary Robust Invariant Scalable Keypoints)
- LLSQ (Local Least Squares)
- SIFT (Scale-Invariant Feature Transform)

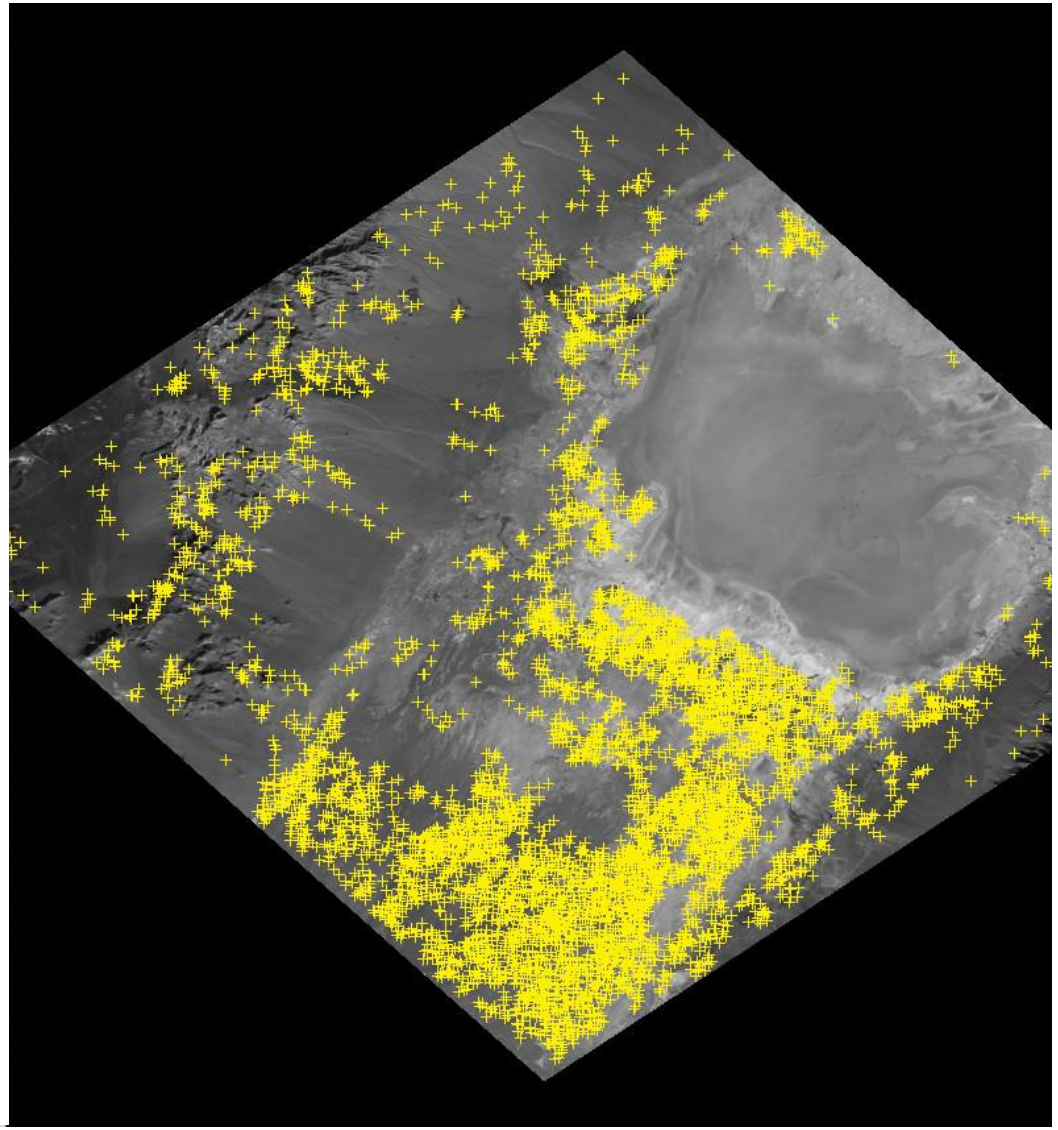
Selected GCP to improve DESIS sensor model (on-the-fly and for boresight calibration)
Others are used for Quality Assessment

Railroad Valley, USA
13-12-2018 18:23:11 UTC
38.4467°N 115.7512° W
Sun: 64.14°, 160.58°
Incident Angle: 0.8°










Railroad Valley, USA
13-12-2018 18:23:11 UTC
38.4467°N 115.7512° W
Nye
6
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Google Earth
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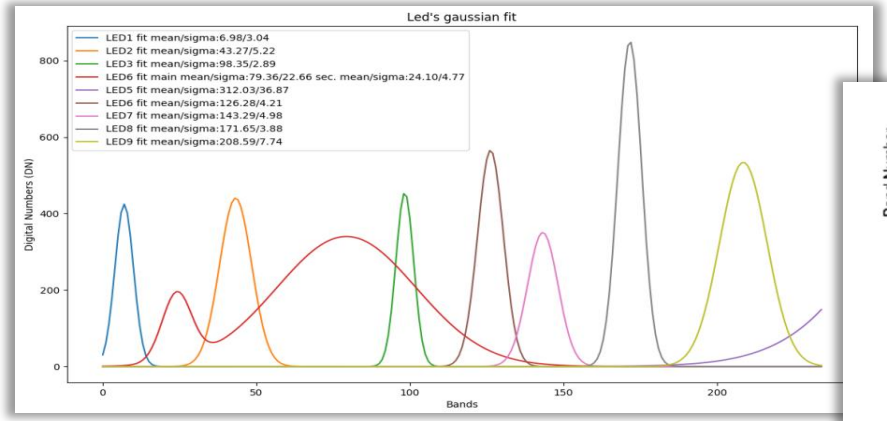
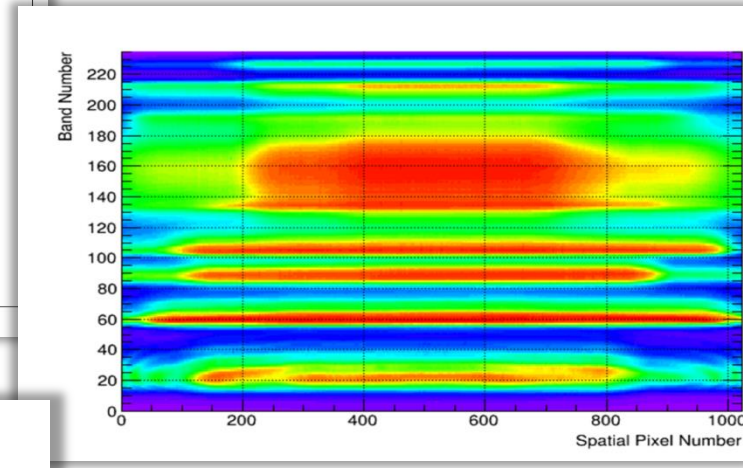
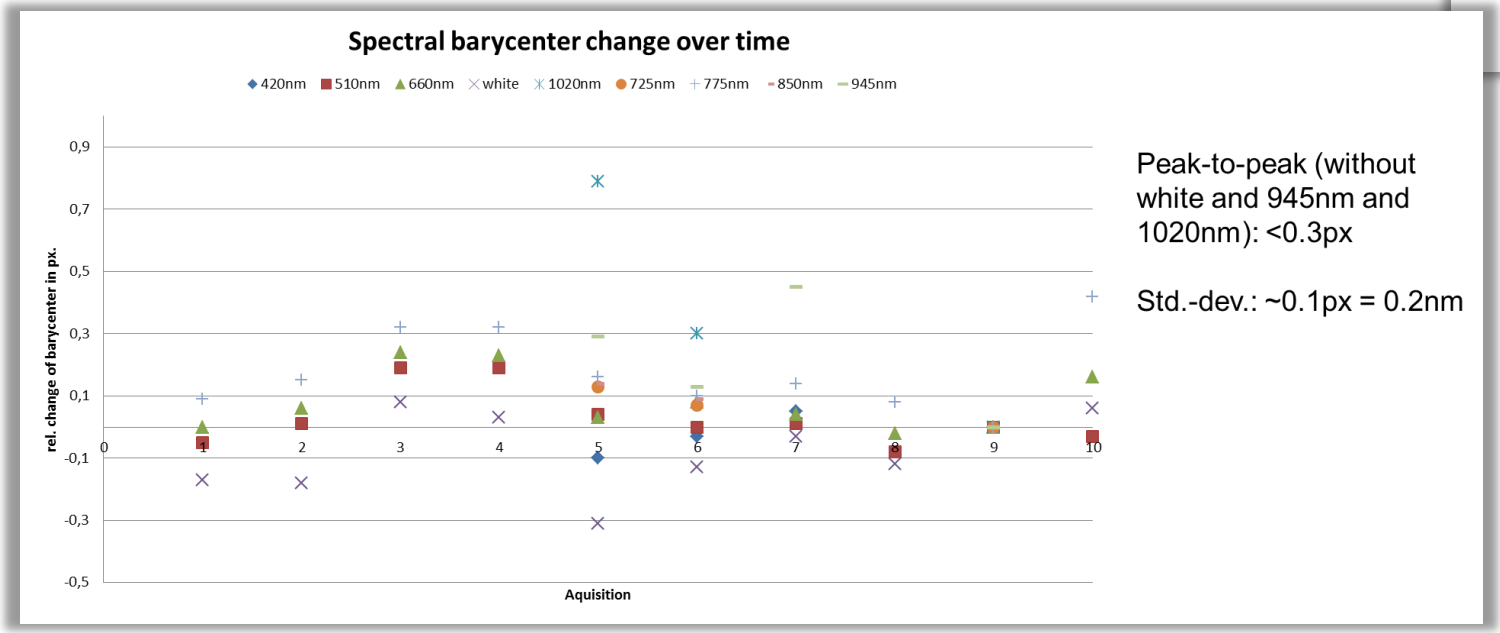
Commissioning Phase Activities – In-Orbit Spectral Characterization

– Using on-board calibration sources (LEDs)
  ✓ – Pre- and post-launch characteristics
  – Incl. temperature stability & other HK / telemetry data







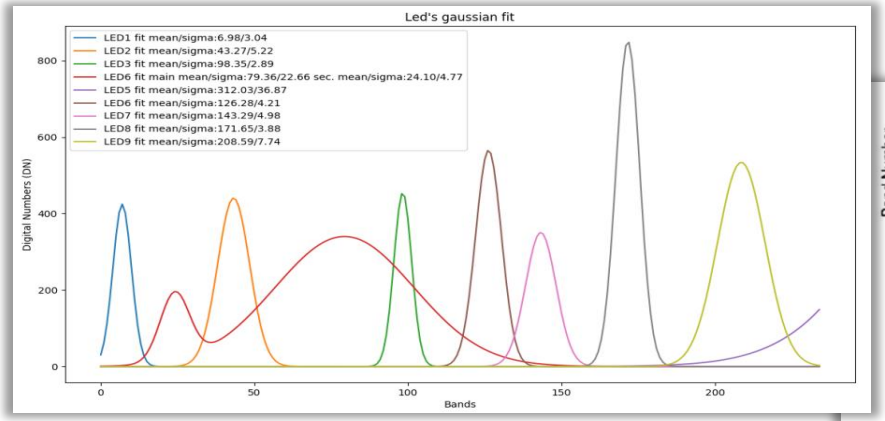
Peak-to-peak (without white and 945nm and 1020nm): <0.3px

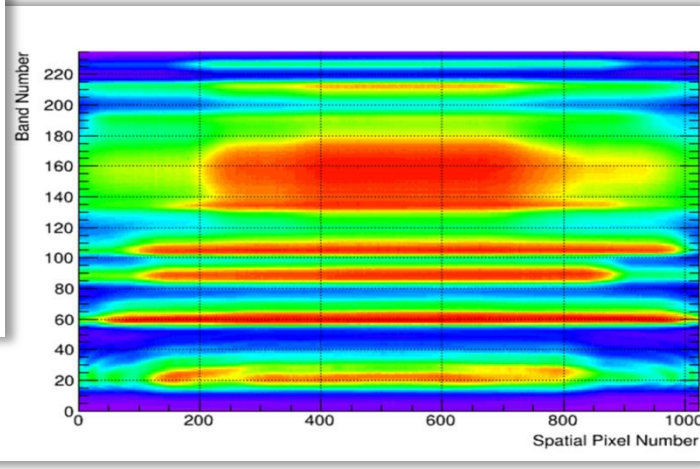
Std.-dev.: ~0.1px = 0.2nm

Commissioning Phase Activities – In-Orbit Spectral Characterization

– Using on-board calibration sources (LEDs)

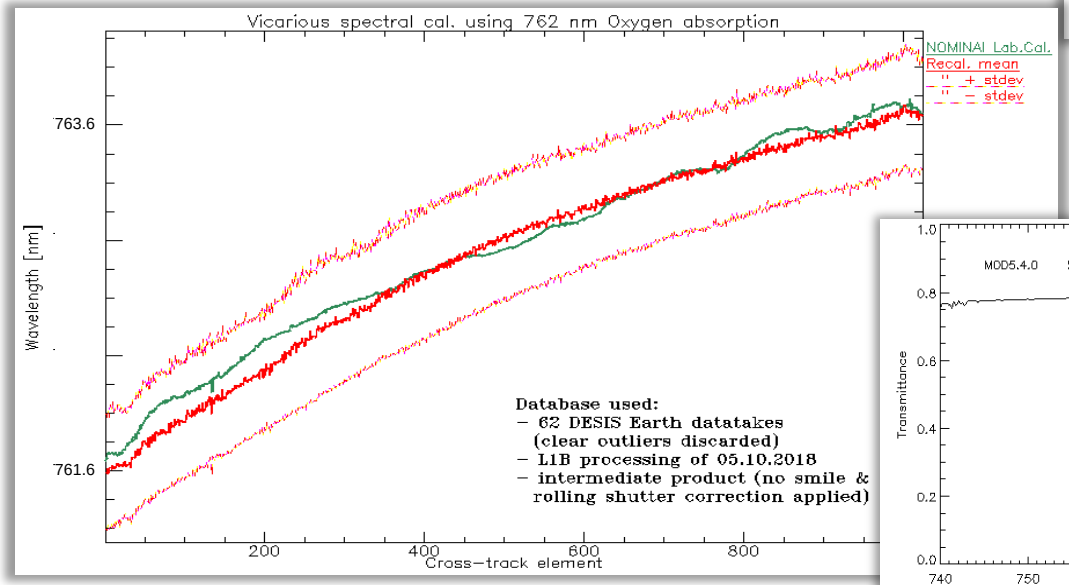
✓
  – Pre- and post-launch characteristics
  – Incl. temperature stability & other HK / telemetry data

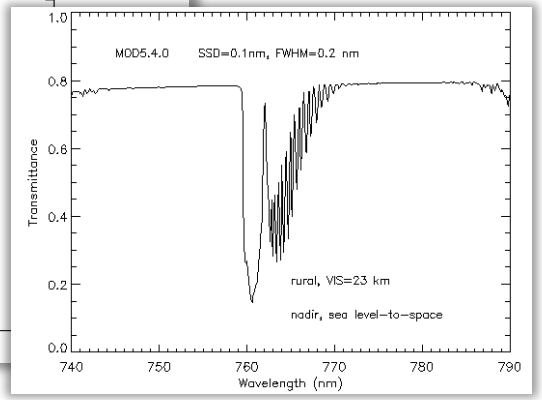




– Using atmospheric absorption features

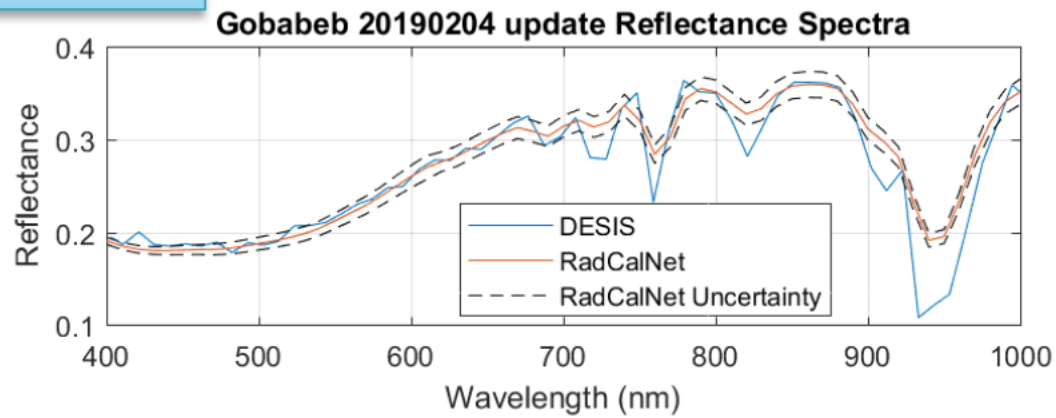
✓
  – Smile pre- and post-launch

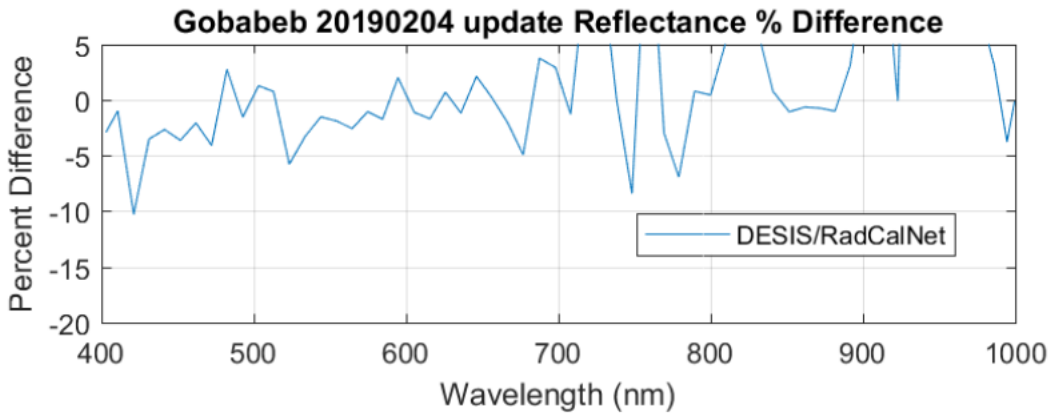




RadCalNet Hyperspectral Comparison Gobabeb, 2/4/19

L1B TOA Reflectance
% Diff = 100*(1 – DESIS/RadCalNet)





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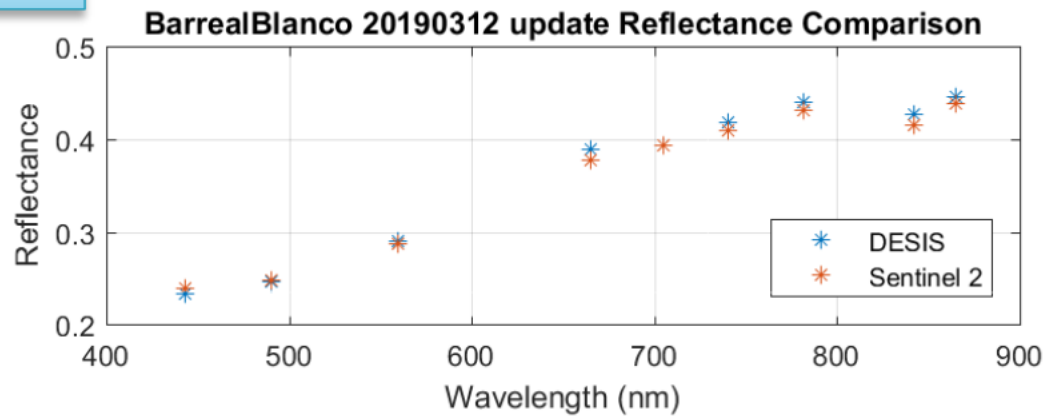
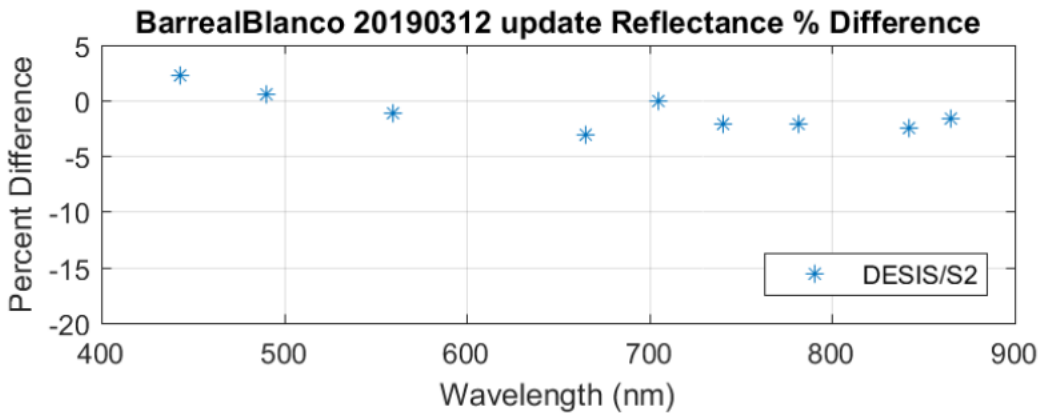
Sentinel-2 Comparison
Barreal Blanco, 3/12/2019

L1B TOA Reflectance
% Diff = 100*(1 - DESIS/S2)





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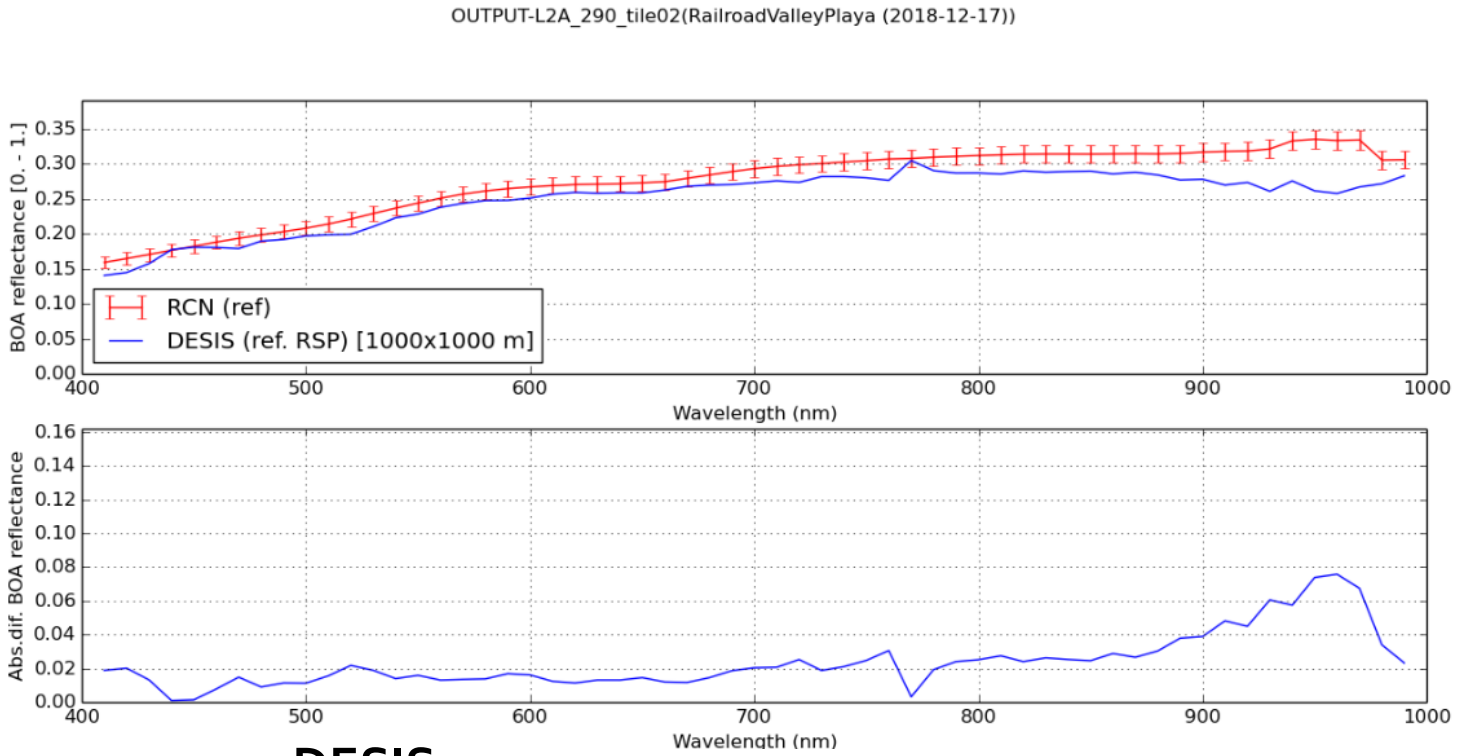
Commissioning Phase Activities – In-Orbit Radiometric Characterization
Atmospheric Correction



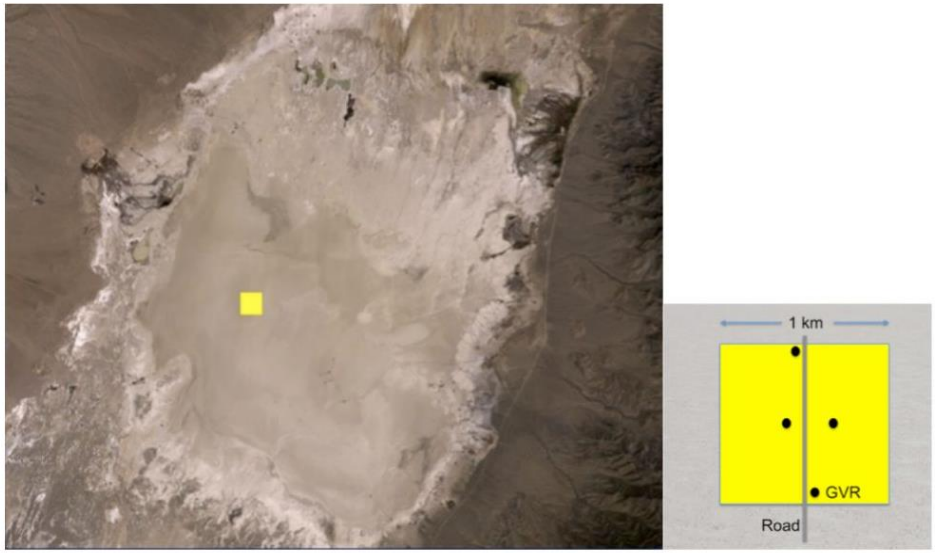


Figure 1: The Railroad Valley Playa and the target for which the RadCalNet top-of-atmosphere reflectance spectra are representative (yellow).

DESIS scene

Time of acquisition: 13.12.2018, 18:21:18 UTC
SZA = 64°
Incidence = 0.8° (**nadir**)
No BRDF correction

RadCalNET data

Time of acquisition: 17.12.2018, 18:30 UTC

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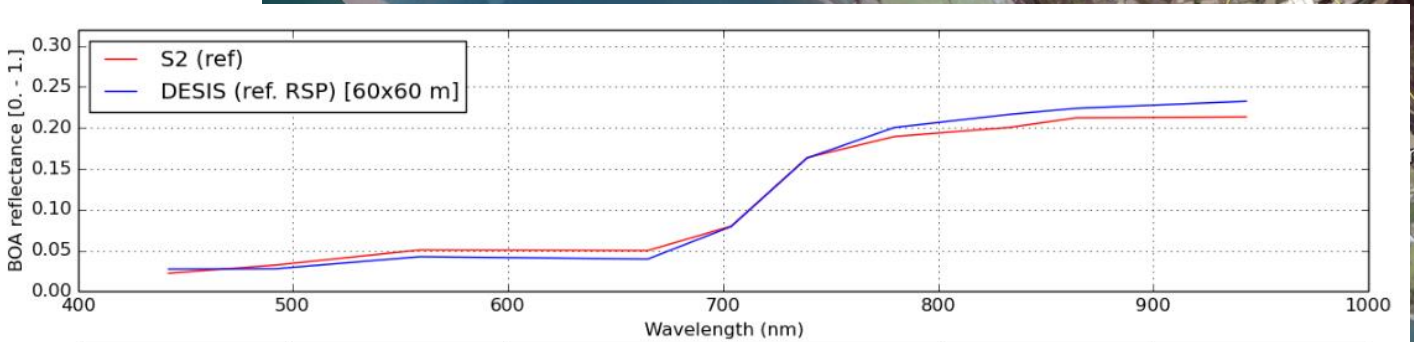
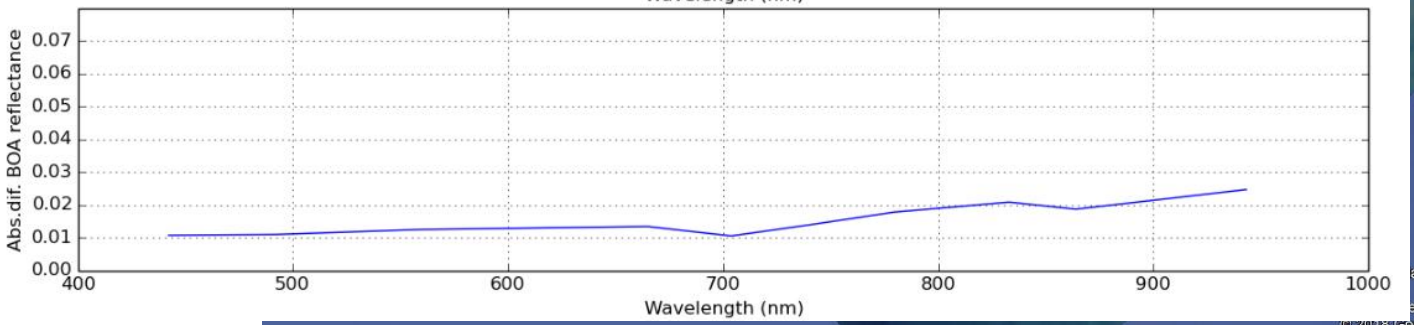
Comparison Sentinel-2 DESIS

La Crau, France

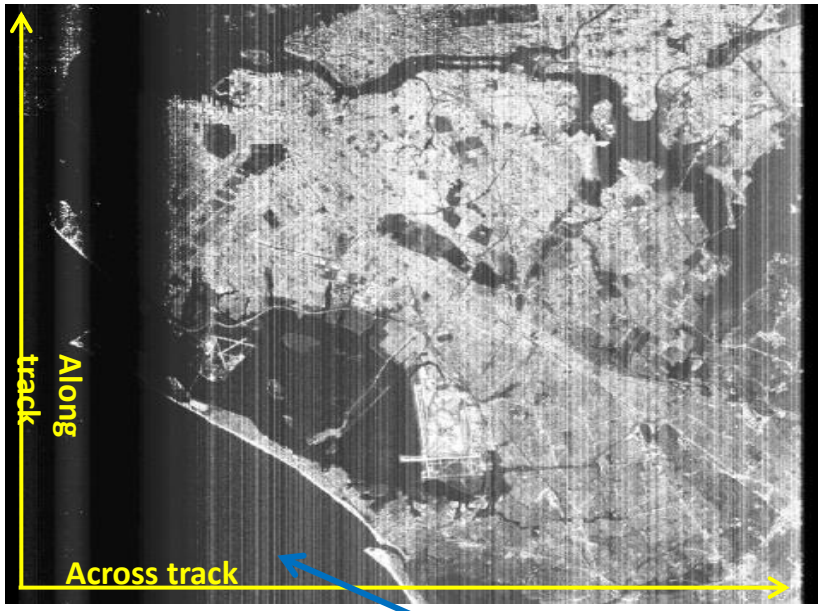
04-02-2019
13:47:04 UTC



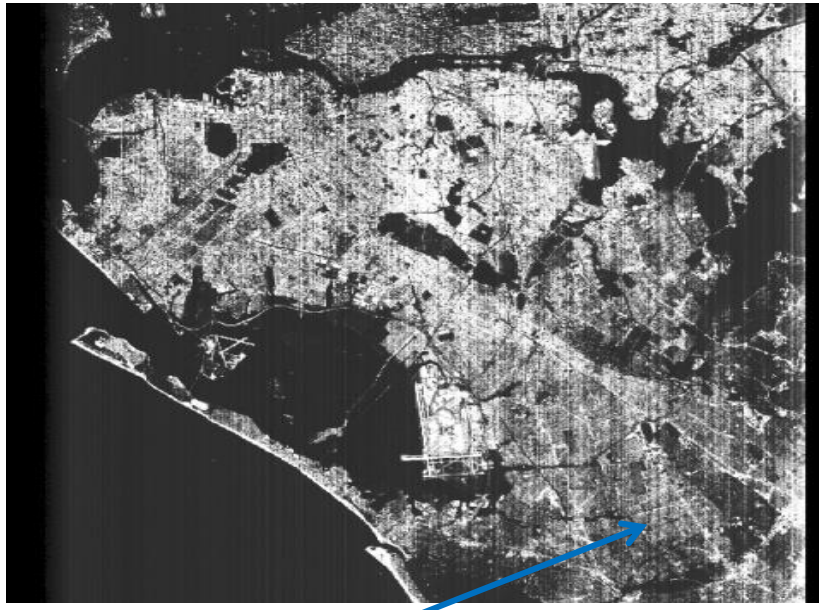


Striping - solvable

Band 1 (2.55 nm)



Band 4 (2.55 nm)

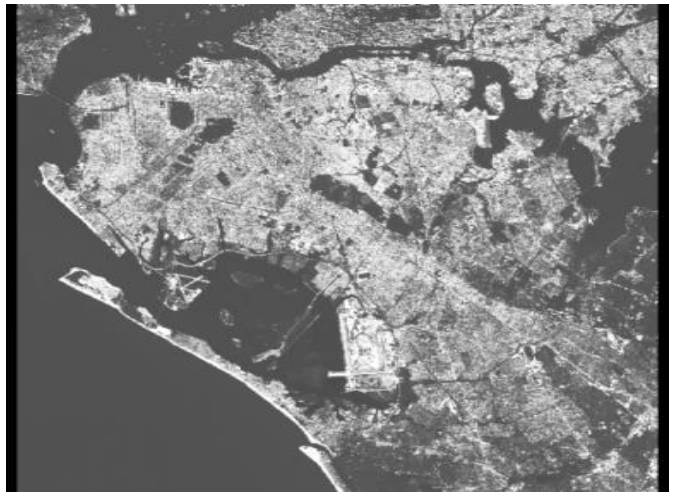


Band 22 (2.55 nm)

Striping

Most likely caused by PRNU coefficients, most noticeable in first ~30 bands (2.55 nm)

Band 100 (2.55 nm)



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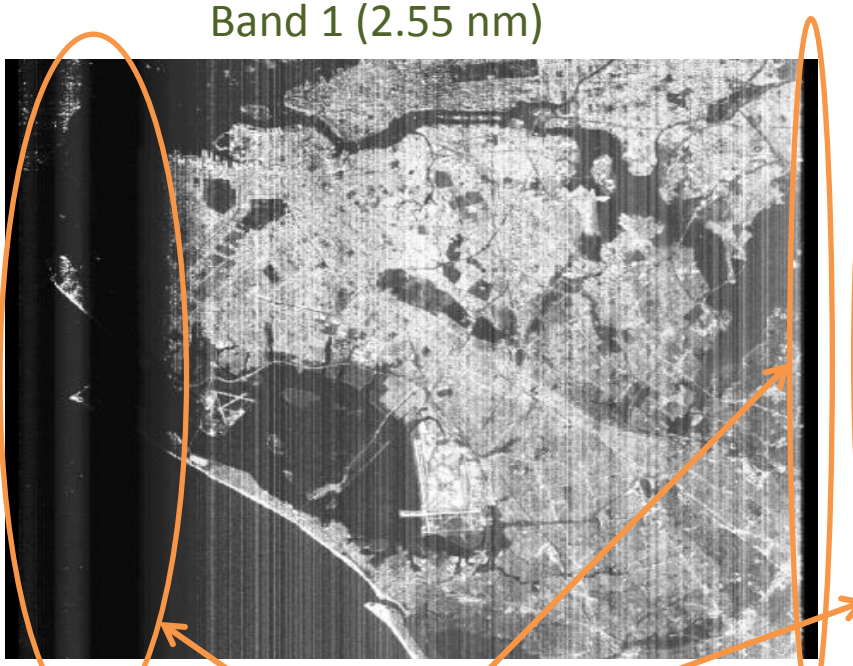
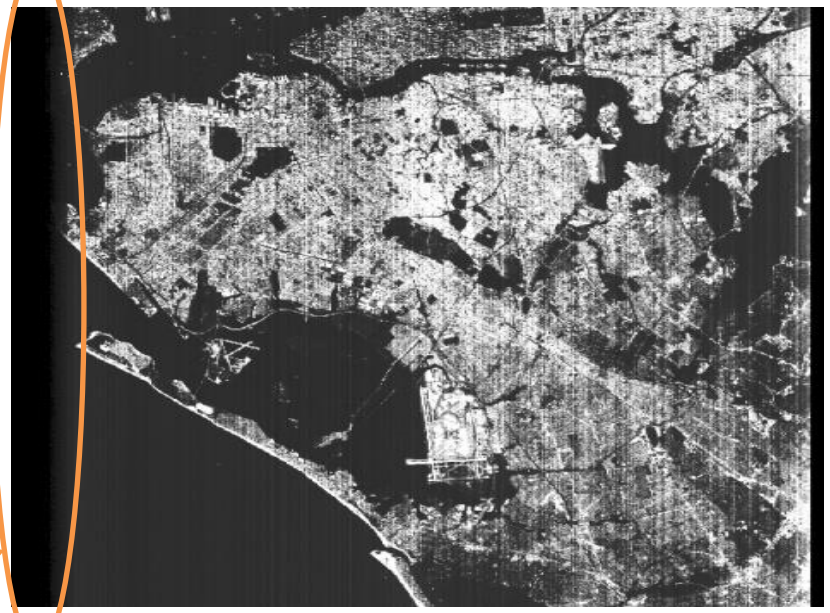
Striping – not solvable

Band 1 (2.55 nm)



Band 4 (2.55 nm)



Band 22 (2.55 nm)

Manufacturing defects

Different Striping

Most likely caused by Noise in DC, most noticeable in last ~30 bands (2.55 nm). Notice also horizontal striping of same magnitude. Cosmetics solution could be used, but not real solution

Band 212 (2.55 nm)

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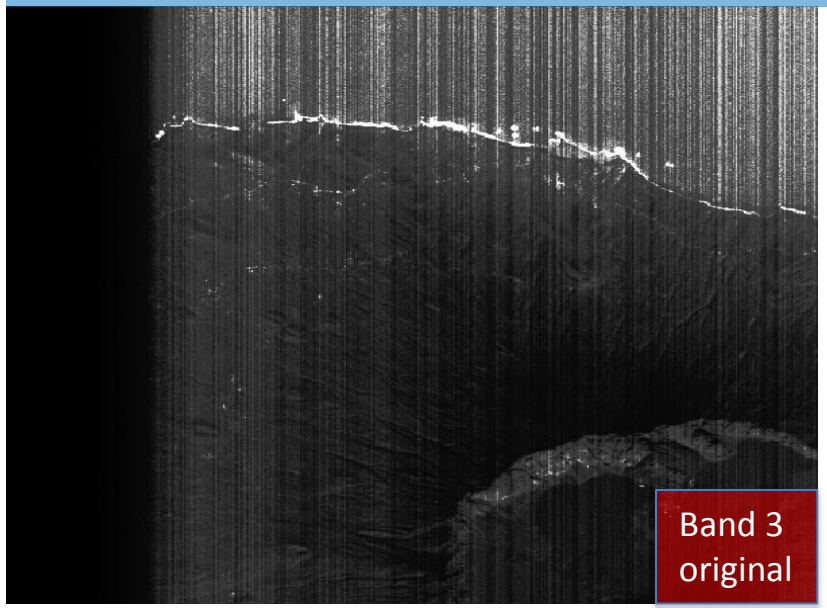
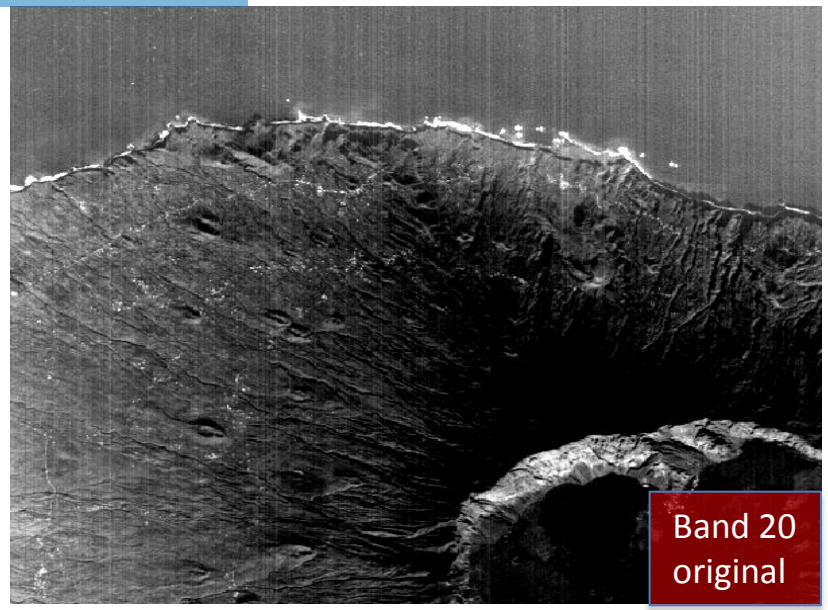
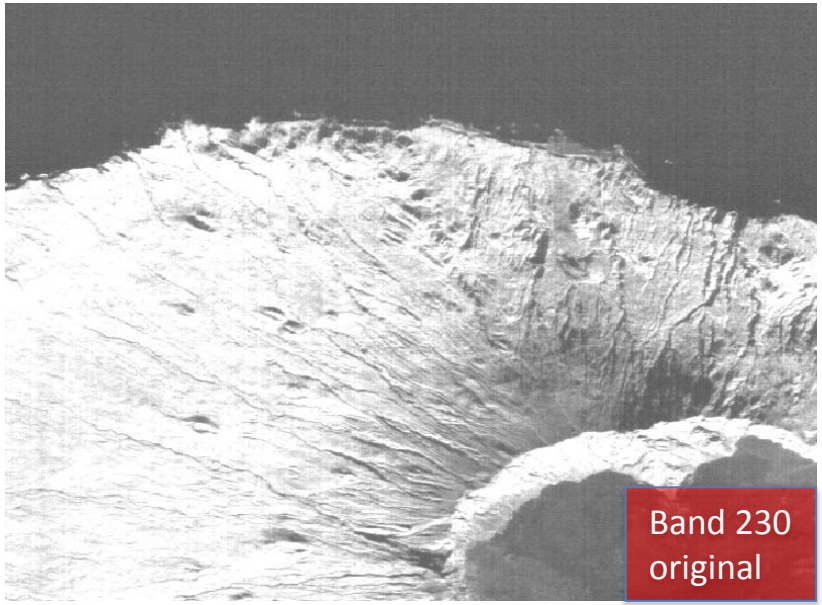
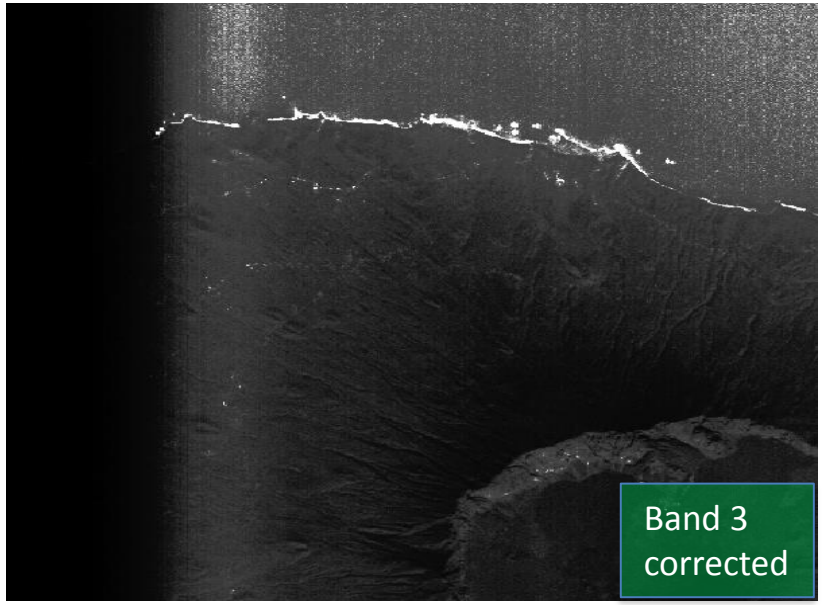
Comparison Original / Corrected

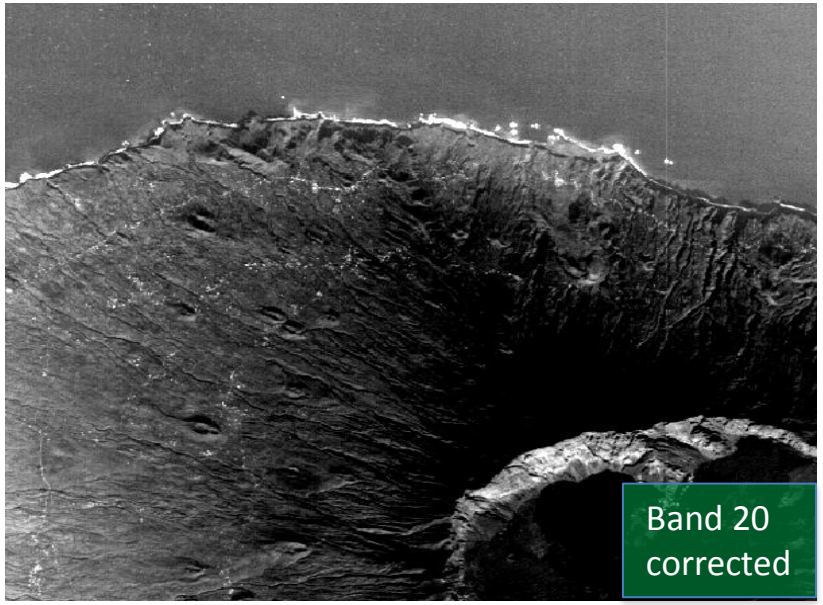
L1B radiance range stretched to highlight striping

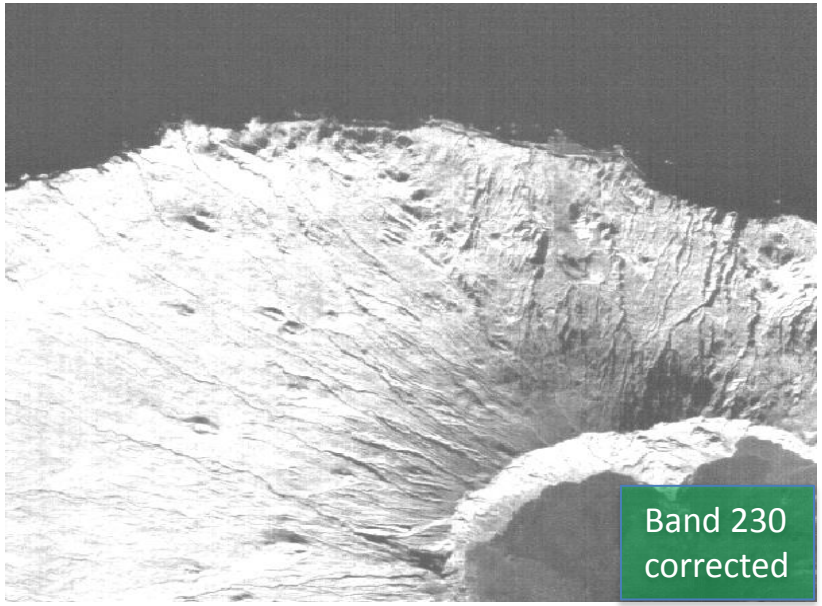




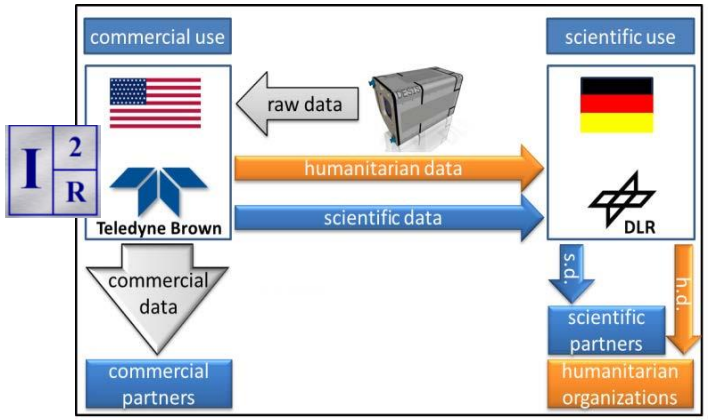








Data Policy



DESIS is to be operated by Teledyne (TBE):

- TBE will receive the raw data
- TBE has the exclusive right to license or transfer image data for commercial use.

For scientific and humanitarian purposes, DLR has the right to:

- Task DESIS, 2000 minutes/year
- Request archived data

Distribution of 2.55 & 5.1 nm spectral sampled data is subject to NOAA approval

- For scientific purposes only:
  - **DLR can share DESIS scientific data with other scientific organizations within projects; Data are free in this case for the partners**

  - Scientific use includes:
    - basic and application oriented research,
    - projects by national and international educational or research institutions or by governmental institutions,
    - development and demonstration of future applications for scientific and/or operational use and
    - preparation and execution of government-funded education, research and development programs.

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Summary and Conclusions and Outlook

- DESIS in-orbit functional tests successful
- Main findings during commissioning phase
  - Very few defective / unstable pixels (0.3%)
  - Temperature stability well within specification
  - Very high DC stability (~3%)
  - Processing chain up and running to L2A (rad. & geom. & atm.)
    - Including smile & rolling shutter correction
  - Geometric accuracy within 1 pixel (image-to-image matching)
  - Spectral characteristics consistent pre-/post- launch
  - Radiometric characterization ongoing
  - On-board calibration procedure ongoing
- Outlook
  - Cross-calibration with HISUI foreseen
  - Multispectral instrument DECAM planned (fusion HSI and MS)